RF source selection for the ILC

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RF source selection for the ILC

- Background
- High-volume manufacturing: accommodating peak demand
  - VKS-7964M for XM-Radio
  - VKP-8291A for SNS
- Available sources for the ILC
  - VKL-8301 TESLA MBK
- Second-generation sources for the ILC
  - MBK
  - HOM IOT
    - VHP-8330A
    - ILC HOM IOT
- Conclusion

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High Volume Manufacturing

VKS-7964M developed for Satellite Digital Audio Radio

Both Exhaust and Test were identified as production bottlenecks

Parameter	**Value**	**Units**
Power Output	3.0* / 10.0**	kW
Beam Voltage	13.8	kV
Beam Current	1.95	A
Supply Power	14.0	kW
Efficiency	21* / 46**	%
Collectors	4	
Frequency	2338	MHz
1dB Bandwidth	8	MHz
Saturated Gain	45	dB
Cooling Method	Air	
Coolant Flow Rate	1500 / 680	lb/hr / kg/hr
Pressure Drop	3.5 / 0.87	in/H_2O / kPa
Total Weight	275 / 125	lbs / kg

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* Customer operating point ** Saturation

High Volume Manufacturing

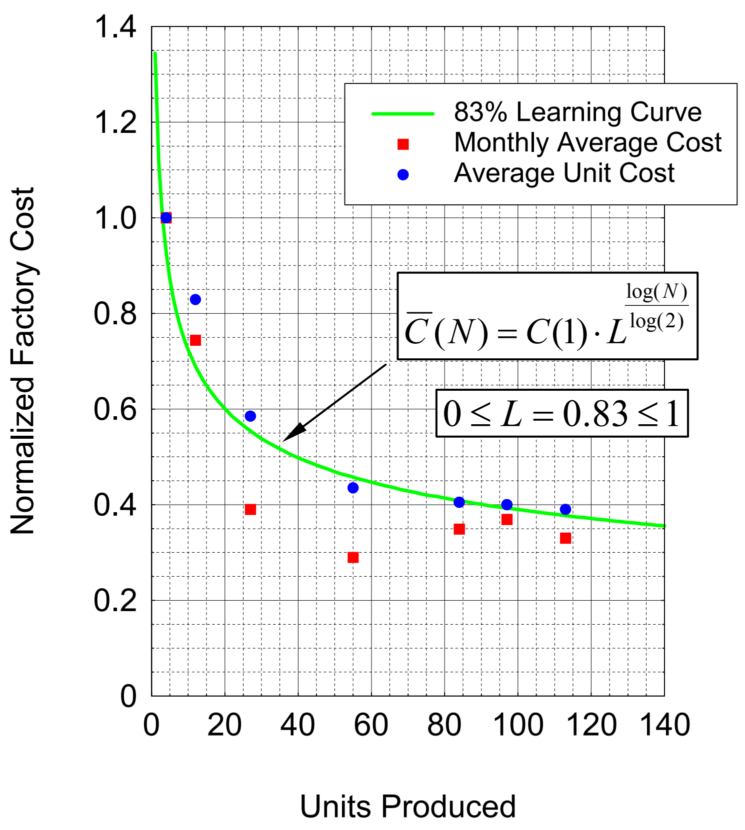
VKS-7964M: breaking the Exhaust bottleneck

A multi-port exhaust manifold was used

DFA/DFM methodology critical to our success; 83% learning curve realized

Delivery was as high as 12 per week, however we were asked to reduce to 10 per week due to Amplifier manufacturing constraints

250 units produced



Capacity: 600 /yr

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High Volume Manufacturing

VKS-7964M: breaking the Test bottleneck

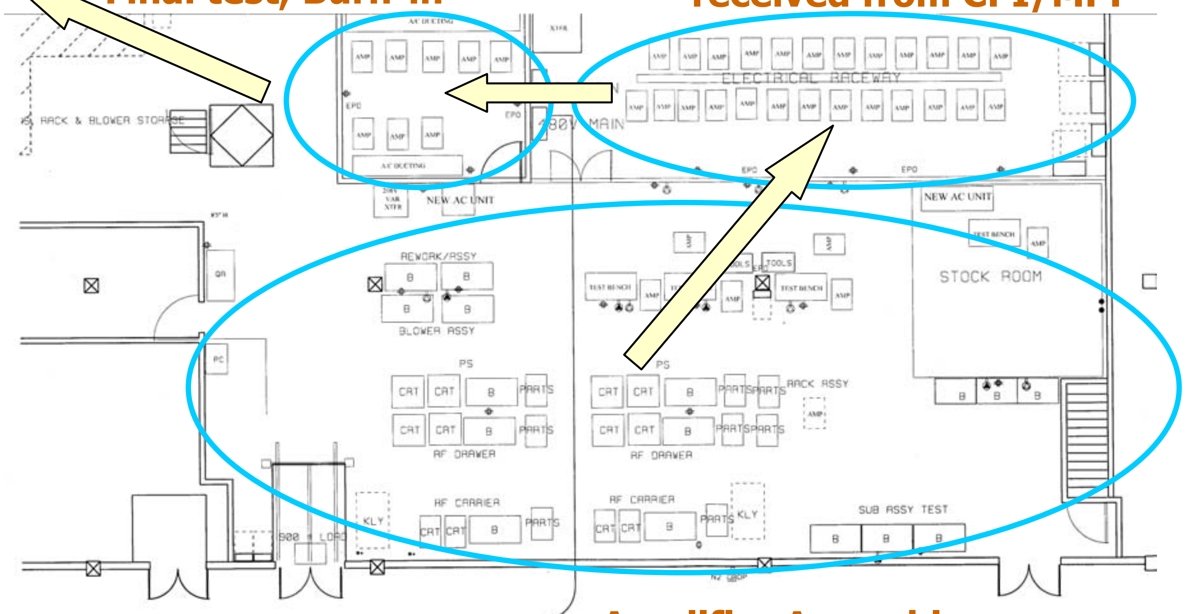
Tubes conditioned and tested in deliverable amplifiers

One amplifier was retained at the end of the program for test

This model would make sense for ILC

CPI/Satcom
Final test, Burn-in

First test: Green tubes received from CPI/MPP



Amplifier Assembly

Capacity: 500 /yr

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Photo and Layout courtesy of CPI-Satcom

High Volume Manufacturing

VKP-8291A developed for SNS*

Exhaust identified as the only Production bottleneck

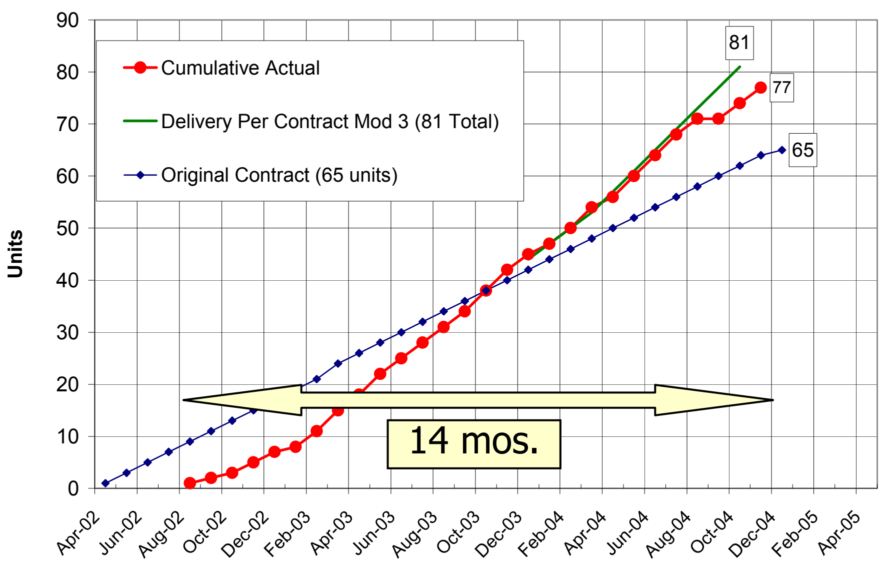
Parameter	**Value**	**Units**
Peak Power	550	kW (min)
Average Power	50	kW (min)
Beam Voltage	76.5	kV (max)
Beam Current	11.5	A (max)
Efficiency	65	%, min
Frequency	805	MHz
RF Duty Cycle	9	%
RF Pulse Length	1.5	ms
Gain	50	dB (min)

*Work supported by LANL and ORNL

High Volume Manufacturing

VKP-8291A:breaking the Exhaust bottleneck

Exhaust capacity was found to limit our goal of producing 1 unit per week. A dual-port exhaust system overcame the bottleneck



Capacity: 52/yr

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VKL-8301 TESLA MBK*

- **Background**
  - MBK developed for the TESLA V/UV-FEL, X-FEL
  - Candidate ILC Source
  - TESLA approach: one MBK will feed 36 Superconducting cavity cells (3 cryomodules with 12 cavities per)
  - HOM Technology; TM_{020} cavities
  - Factory CSI complete
  - Delivered to DESY

*Work supported by DESY

VKL-8301 TESLA MBK

- **Design Highlights**
  - Confined-flow focusing
    - State-of-the-art focusing system developed for off-axis electron beams*
  - High order Mode (HOM) Technology: TM_{020} Cavity
    - Proven high-power capabilities
    - No RF breakdown observed
    - Stable; No oscillations observed

*Domestic patent granted, Foreign patent pending

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VKL-8301 TESLA MBK

Test Results Compared to Klystron Specification

Parameter	Measurement	Specification
Frequency	1.3 GHz	1.3 GHz
Peak Power Output	10 MW*	10 MW
Ave. Power Output	150 kW	150 kW
Power Asymmetry	0.7 %	≤ 5 %
Efficiency	59 %	65 % (goal)
Beam Voltage	120 kV	≤ 120 kV
Beam Current	141 A	≤ 150 A
Microperveance	3.4	≤ 3.6
RF Pulse Length	1.5 ms	1.5 ms
Saturated Gain	49 dB	≥ 47 dB
Cathode loading	2.2 A/cm^2	- - -
Body Current (DC)	0.6 A	- - -
Body Current (Sat)	3.6 A	- - -

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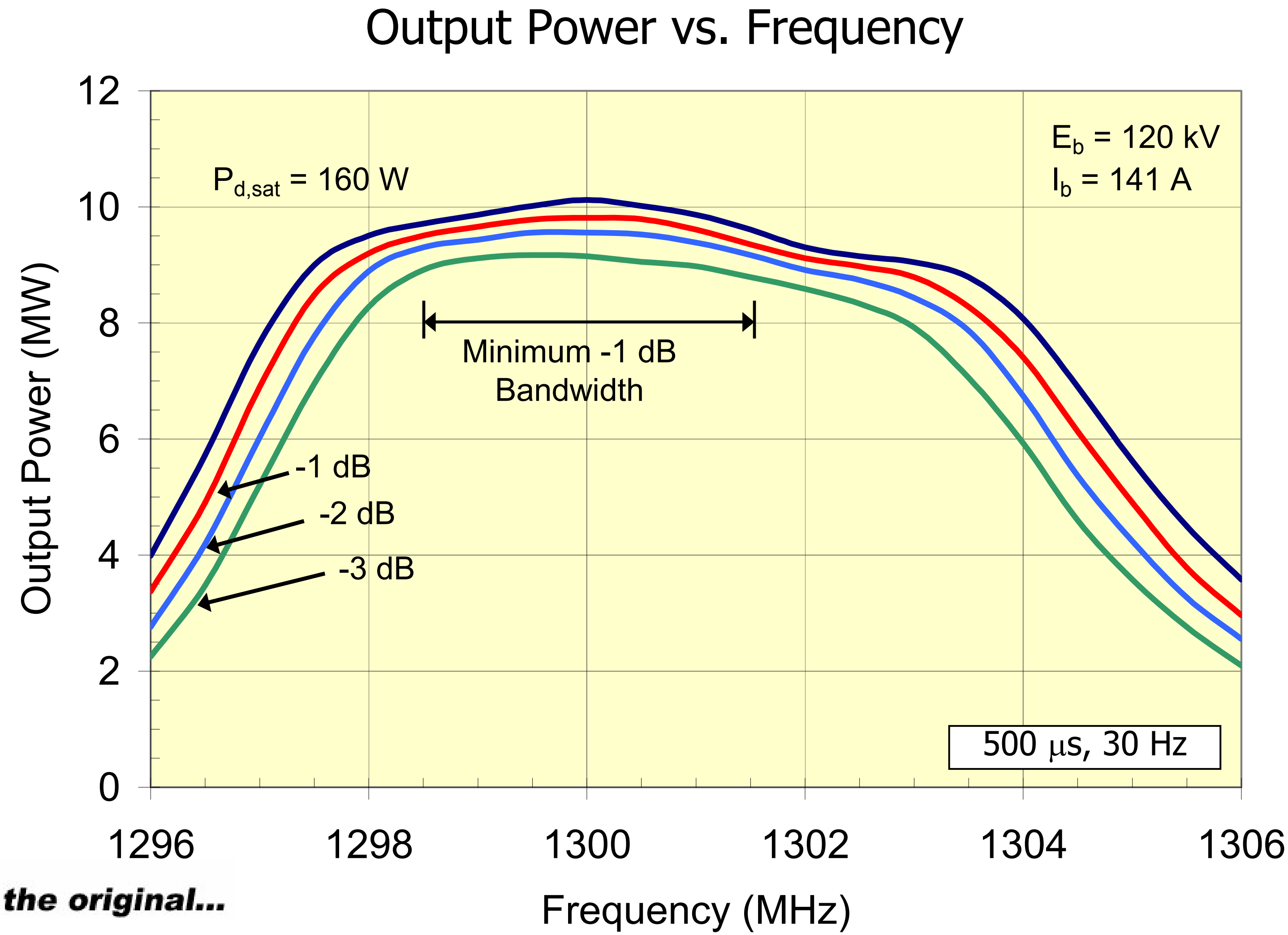
*Officially name-plated at 9 MW due to power supply switch and load problems
Higher power levels were achieved at 500 μs, 30 Hz

VKL-8301 TESLA MBK



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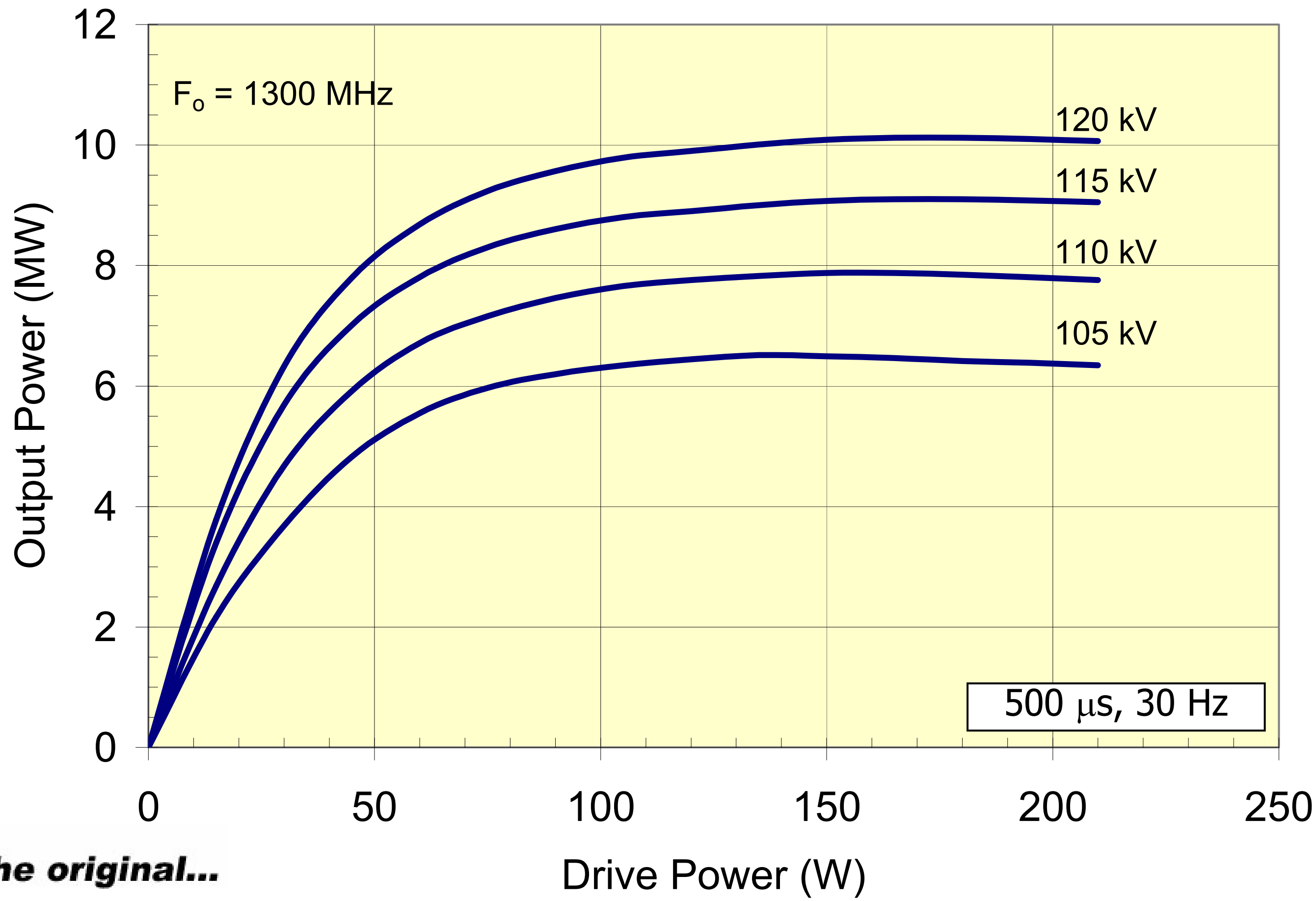
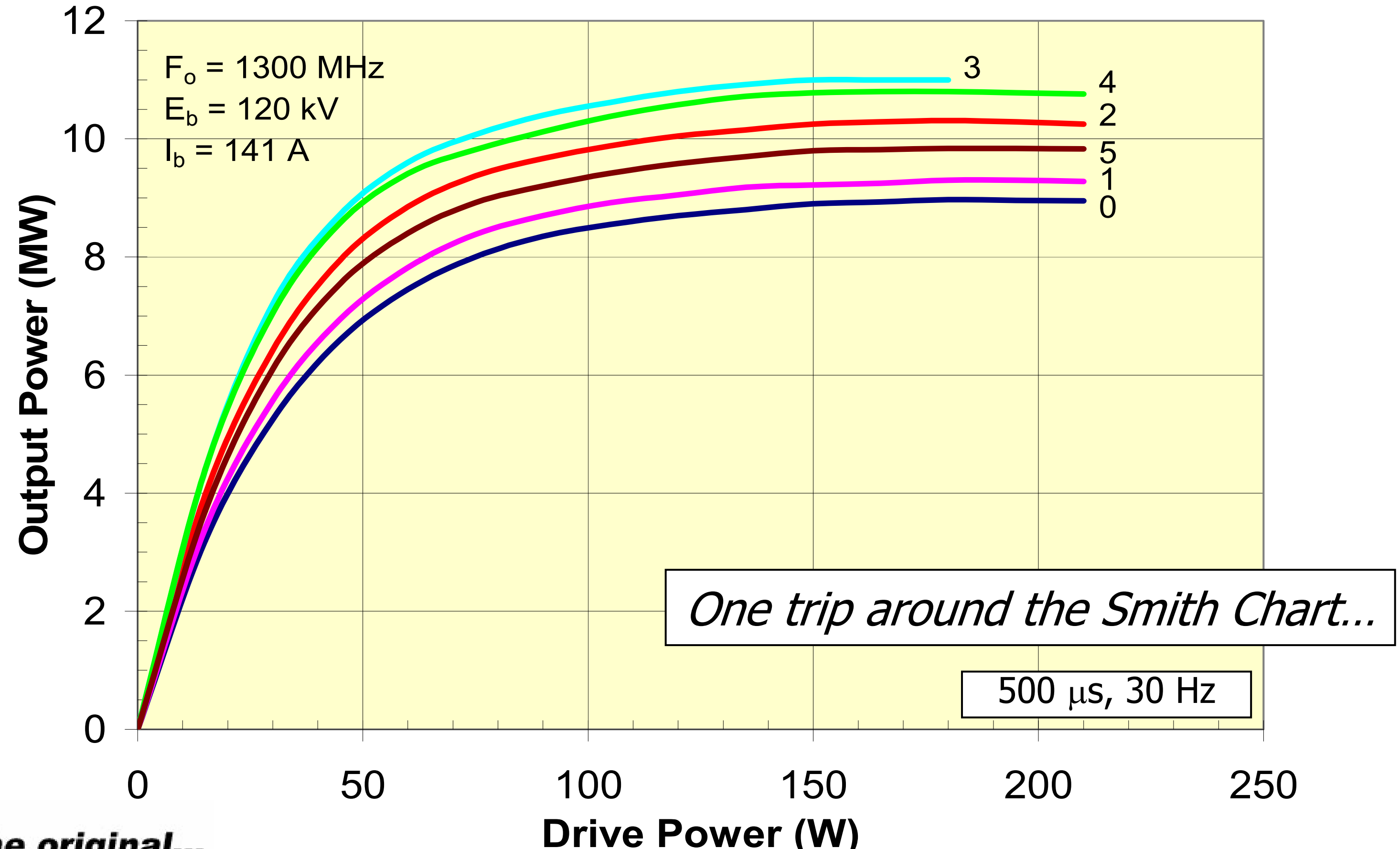
VKL-8301 TESLA MBK

Output Power vs. Drive Power for Various Beam Voltages



VKL-8301 TESLA MBK

Output Power vs. Drive Power Variation into a 1.2:1 VSWR Mismatch



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VKL-8301 TESLA MBK

- The VKL-8301 MBK successfully demonstrated confined-flow technology for multiple off-axis electron beams
- The next steps are:
  - Realize the 65% efficiency level
    - Analysis is underway now
    - Implement this change on the next MBK
  - Design and fabricate TESLA X-FEL horizontal version
  - A contract for more…

Second Generation Sources - MBK

- We are delighted with the performance of the VKL-8301 prototype. It should serve DESY well. Here are some interesting observations
  - The VKL-8301 voltage and current were established by existing fundamental mode MBKs
  - The use of TM_{020} cavities approach makes this the largest diameter MBK proposed for TESLA
  - Large cathode bolt-circle of the CPI MBK 'underutilized'; more electron beams can be incorporated into this design
- What would a second generation MBK Look like?

Second Generation Sources - MBK

- Electrically… a 10 MW peak , 150 kW average power device would:

	HM MBK			
Number of Beams	6	12	18	units
Beam Microperveance	0.58	0.8	0.8	$\mu A/V^{1.5}$
Total Microperveance	3.492	9.6	14.4	$\mu A/V^{1.5}$
Voltage	114	76	65	kV
Current	134.7	201.9	237.5	A
Current per Beam	22.5	16.8	13.2	A
Beam-Beam separation	5.50	2.75	1.83	inches
Tunnel Diameter (γa=0.5 rad)	1.019	0.818	0.750	inches
Beam Diameter (60% fill)	0.611	0.491	0.450	inches
Brillouin Field	269	323	326	Gauss
Beam Current Density Jo	11.9	13.8	12.8	A/cm^2
Plasma Reduction Factor	0.185	0.183	0.183	(---)
Reduced Plasma Prop. Factor	4.255	6.303	6.926	deg/in
Circuit Length (I/P to O/P gap)	45.8	30.9	28.1	inches

Second Generation Sources - MBK

- Increasing the number of electron beams will
  - Reduce the tube length by nearly 2 feet
    - RF circuit and magnet 15 to 18 inches
    - Anode housing 2.5 to 3 inches
    - HV seal, if oil insulated 2 to 2.3 inches
  - Reduced X-ray shielding (if required)
  - Reduce up-front and life-cycle costs
    - Lower price (weight reduced, easier job to DFA/DFM)
    - Power supply
    - Labor, material, maintenance
  - Allow the use of air for HV insulation*

* In this case, the HV seal length would not be reduced, and may need to increase with respect to the VKL-8301A

Second Generation Sources – MBK

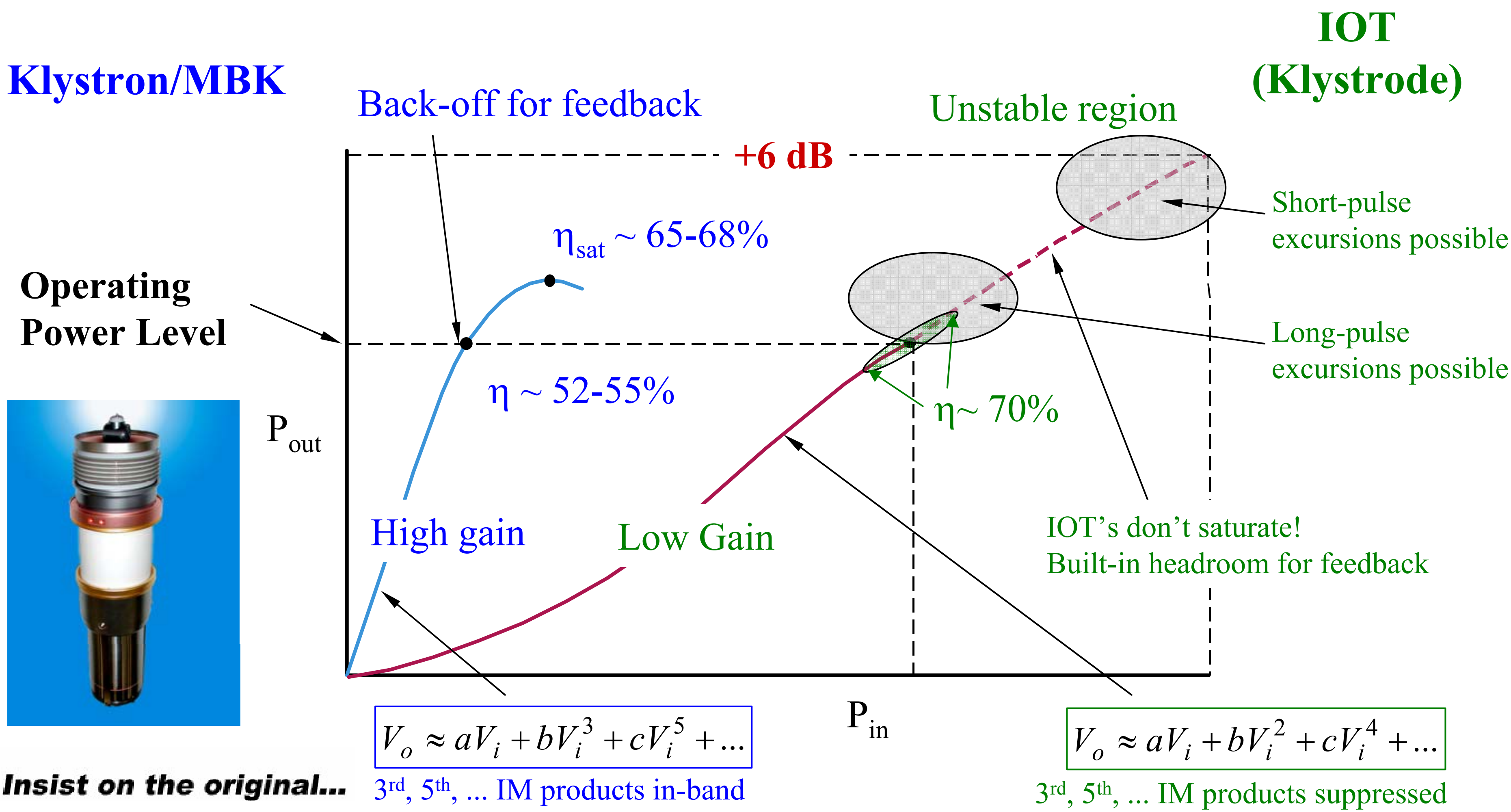
- We've shown that the advanced technology developed for the VKL-8301 can enhance the capabilities of a next generation MBK for ILC
  - TM_{020} cavity technology
  - Confined-Flow Focusing of off-axis electron beams

- These developments open the door for a technology with superior performance characteristics

IOT Technology

- What makes it superior?

- IOT's are the device of choice for commercial UHF broadcast, occupying sockets once held by klystrons. Here's why



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Second Generation Sources – HOM IOT

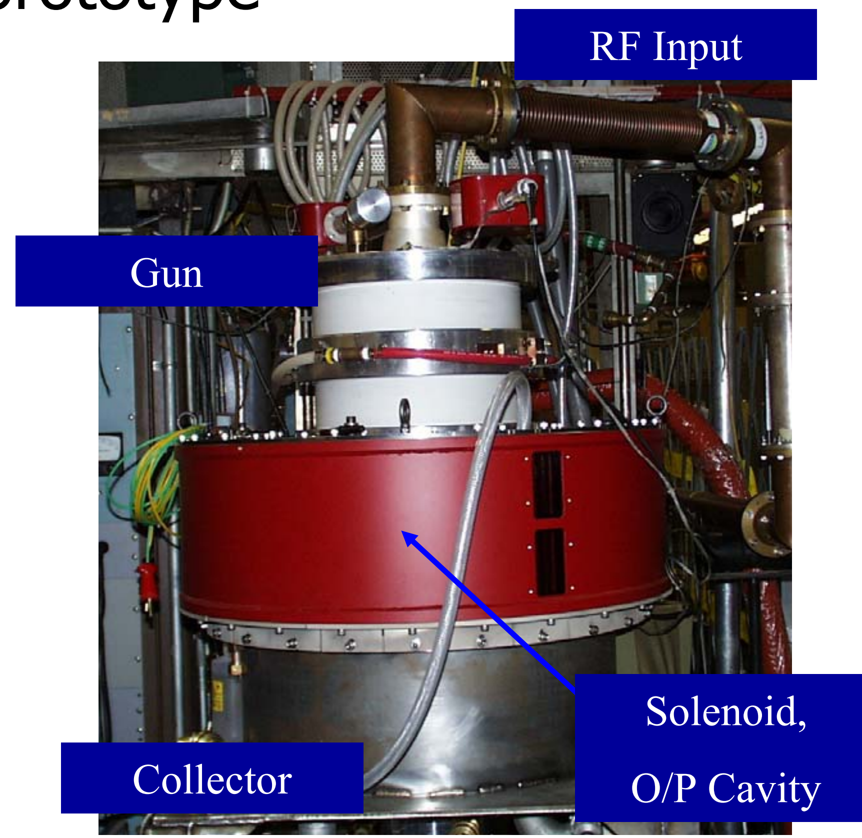
- As mentioned before, the advances made developing the VKL-8301 have direct bearing on the development of an HOM IOT for ILC
  - TM_{020} cavity technology
  - Confined-Flow Focusing of off-axis electron beams
- The HOM IOT considered ‘enabling technology’ for several systems planned by the DoD
- Scientific applications abound
- Next, some background…

IOT Developments – VHP-8330A HOM IOT

- VHP-8330A – Annular beam prototype
  - Developed for APT*

Typical Operating Parameters

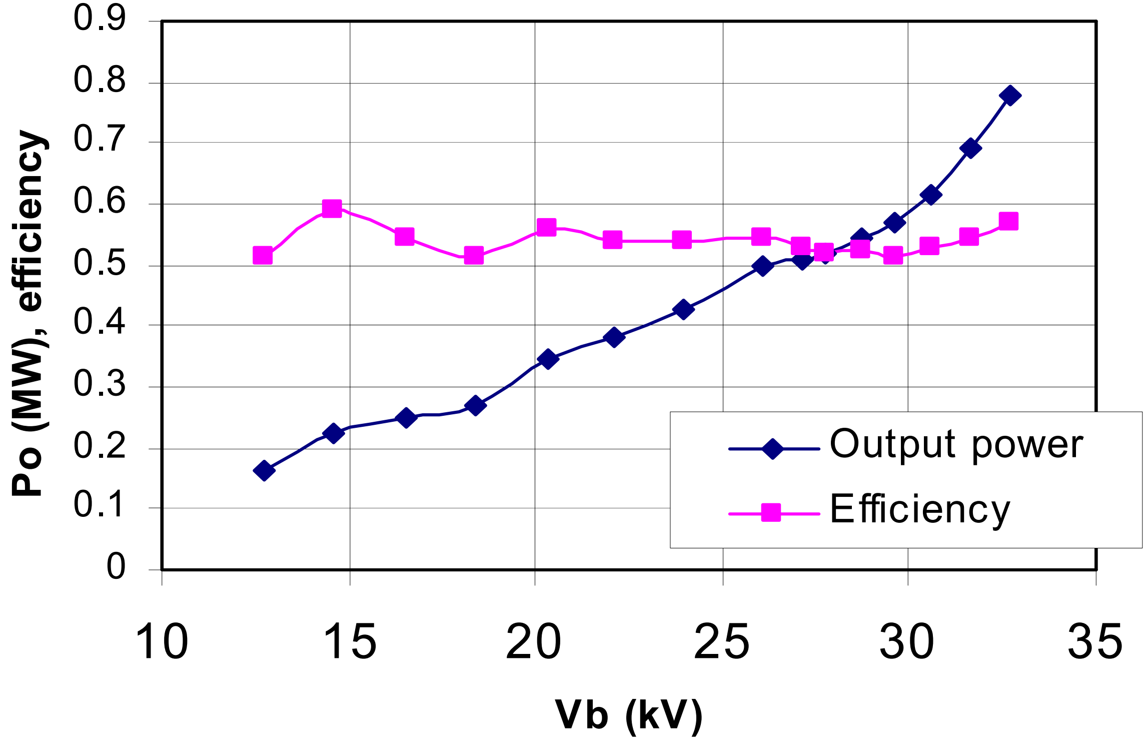
Power Output	1000	kW (min)
Beam Voltage	45	kV (max)
Beam Current	31	A (max)
Frequency	700	MHz
1dB Bandwidth	± 0.7	MHz (min)
Gain	23	dB (min)
Efficiency	71	% (min)
Diameter	30/76	in/cm
Height	51/130	in/cm
Weight	1000/450	lbs/kg
Collector Coolant Flow	220	gpm
Body Coolant Flow	10	gpm
O/P Window Cooling (Air)	35	cfm



*Work supported by LANL

IOT Developments – VHP-8330A HOM IOT

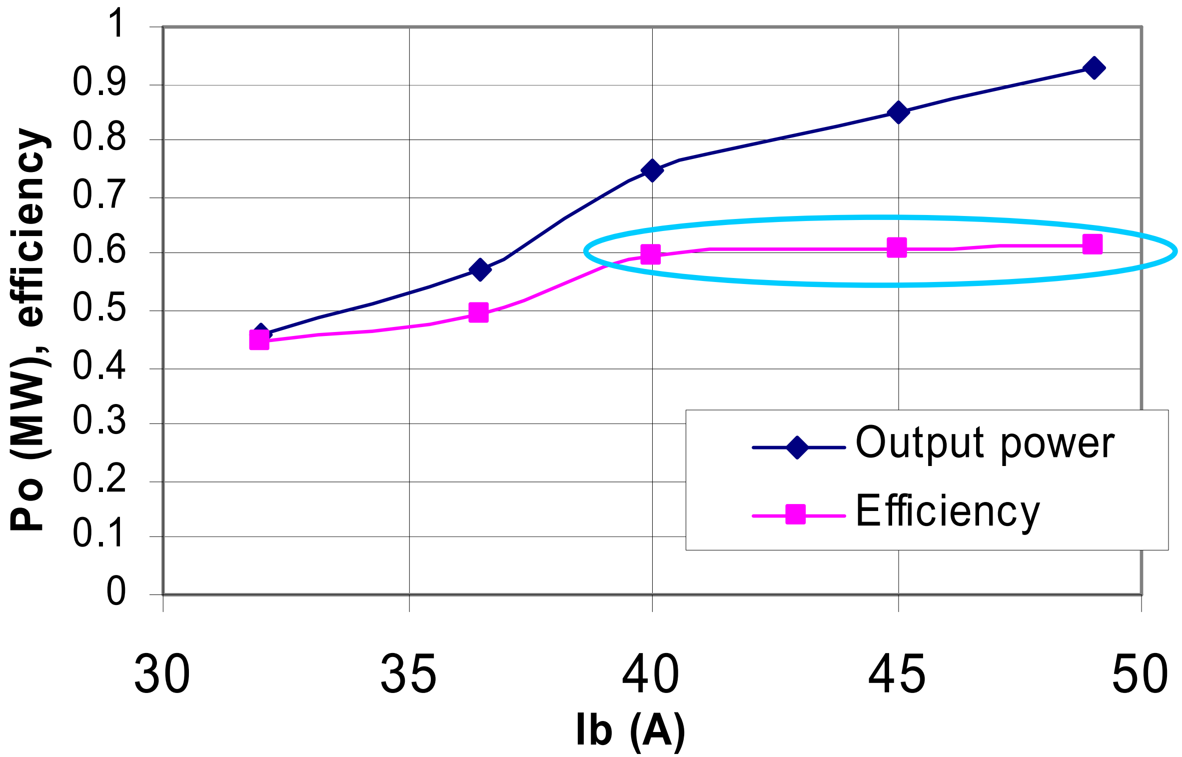
- VHP-8330A – Annular beam prototype, short-pulse



Input power constant at 6 kW

IOT Developments – VHP-8330A HOM IOT

- VHP-8330A – Annular beam prototype, short-pulse



Note: Efficiency remains flat over a broad range of output power levels

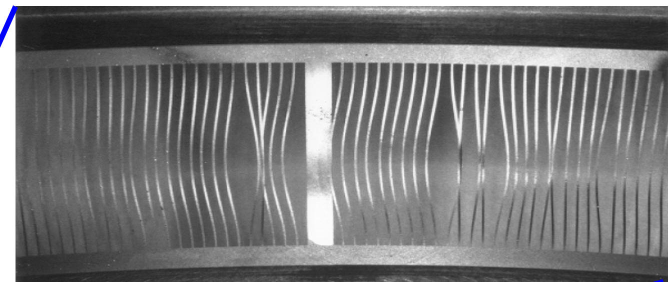
Beam voltage constant at 31 kV

IOT Developments – VHP-8330A HOM IOT

- VHP-8330A – Annular beam prototype
  - Problem
    - The first HOM-IOT project confirmed simulation results to a high degree
    - The annular cathode / grid configuration was mechanically vulnerable during bake-out, leading to grid-cathode short circuits and reduced efficiency during test
  - Solution
    - Replace the annular configuration with a circular arrangement of standard IOT guns. Focusing the electron beams in such a system has become viable through the CPI MBK development for the TESLA V/UV and X-FEL

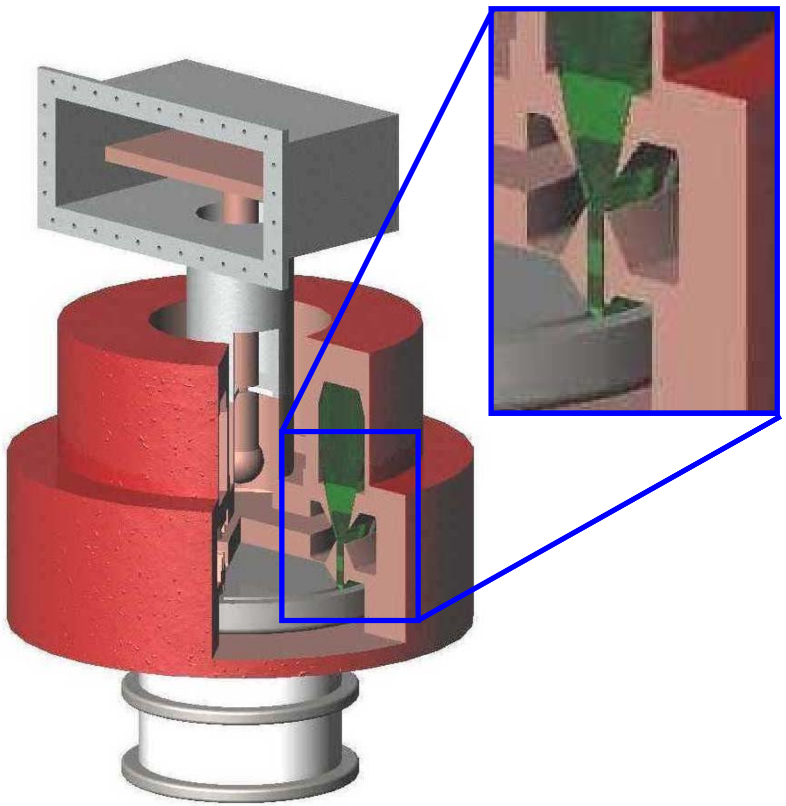
IOT Developments – VHP-8330A HOM IOT

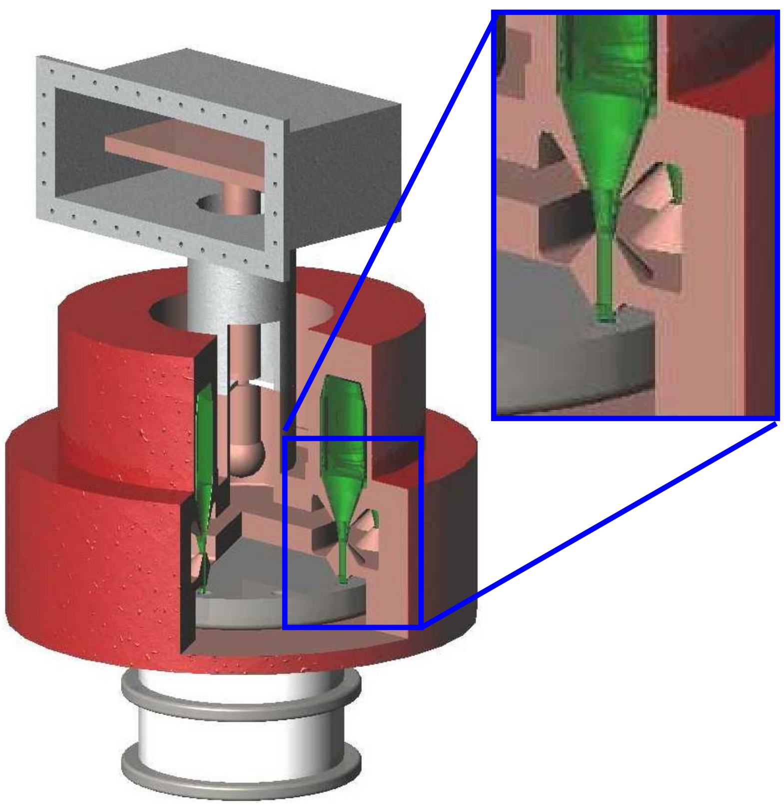
- VHP-8330A – Annular beam prototype
  - These photos show the warping of the HOM IOT cathode grid structure.



IOT Developments – VHP-8330A HOM IOT

- VHP-8330A and VHP-8330B





IOT Developments – VHP-8330B HOM IOT

- VHP-8330B – Round beam prototype

Typical Operating Parameters

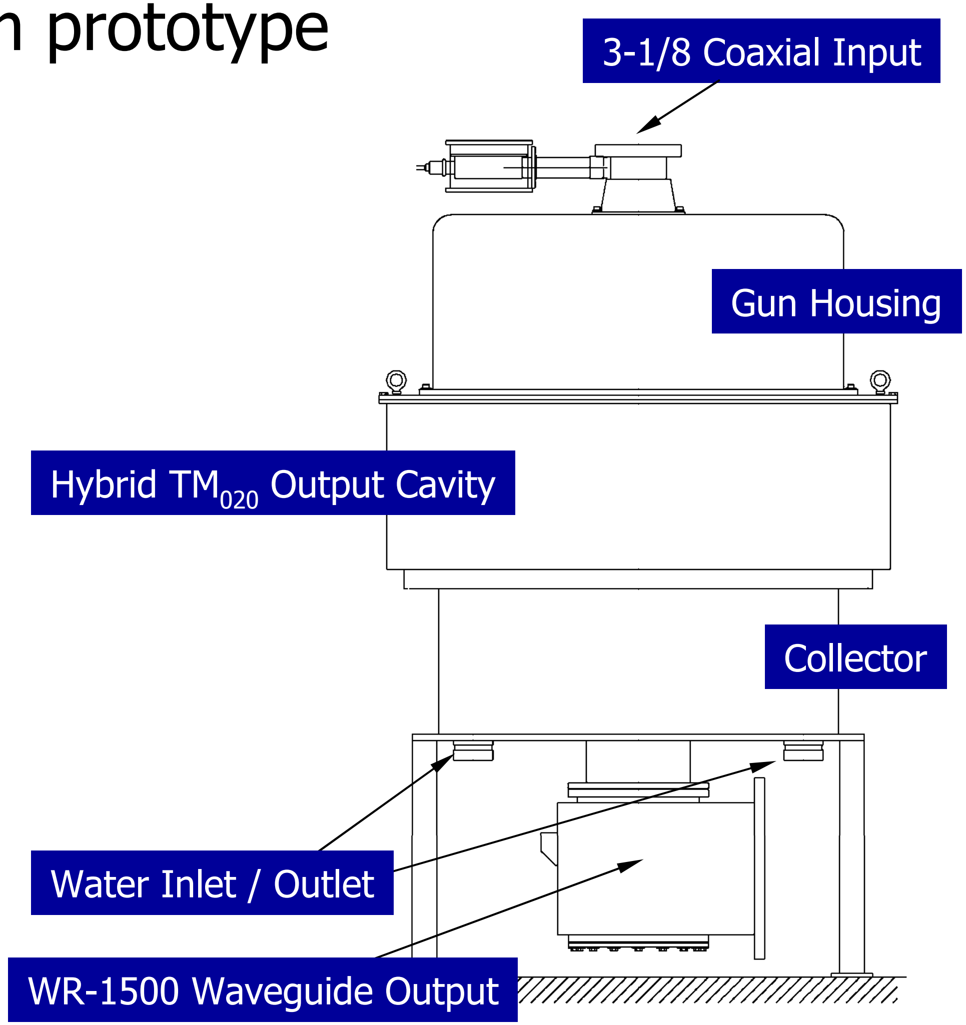
Power Output	1000	kW (min)
Beam Voltage	42	kV (nom)
Beam Current	33	A (nom)
Frequency	650-750	MHz
1dB Bandwidth	6	MHz (min)
Gain	25	dB (min)
Efficiency	71.5	% (min)
Cathode Loading	0.4	A/cm^2

Electromagnet

Main Coil Current	18	A
Main Coil Voltage	49	V

Size

Diameter	30/76	in / cm
Height	51/130	in / cm
Weight	1000 / 450	lbs / kg



IOT Developments – VHP-8330B HOM IOT

- Many opportunities exist…
  - Scientific
  - Military
  - Homeland Security
- HOM IOT will be commonplace in the next ten years
- They will displace klystrons as the device-of-choice for high power UHF and L-band projects, as we've seen in the UHF-TV broadcast market
- What can be done today for ILC?

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Second Generation Sources – HOM IOT

- Performance of a 5 MW HOM IOT for ILC

Peak Output Power	5	MW (min)
Average Output Power	75	kW (min)
Beam Voltage	115	kV (nom)
Beam Current	62	A (nom)
Current per Beam	5.17	A (nom)
Number of Beams	12	---
Frequency	1300	MHz
1dB Bandwidth	4	MHz (min)
Gain	22	dB (min)
Efficiency	70	% (nom)
Solenoid Power	1	kW
Cathode Loading	1.0<	A/cm^2

How would the ILC benefit from this technology?

Second Generation Sources – HOM IOT

- Let's Compare…

HOM IOT
72% smaller cooling system

HOM IOT
60 kW prime
power savings

Parameter	TESLA MBKs	Second Generation CPI MBK	Qty 2 HOM IOT	units
Output Power	10	10	2x 5	MW
Operating Output Power	**8**	**8**	**8**	MW
Average Output Power	150	150	2x 75	kW
Beam Voltage	115	65	115	kV
Beam Current	134	238	2x 62	A
Gain	45	45	22	dB
Number of Beams	6 to 7	18	2x 12	---
Beam Power	15	15	14	MW
Average Beam Power	231	231	214	kW
Collector Power	231	231	64	kW
Operating Collector Power	**111**	**111**	**51**	kW
Efficiency	65%	65%	70%	---
Operating Efficiency	**52%**	**52%**	**70%**	---
Operating Supply Power	**231**	**231**	**171**	kW
Device Class	Class A	Class A	Class C	---

Maximum ratings **Operation**

Second Generation Sources – HOM IOT

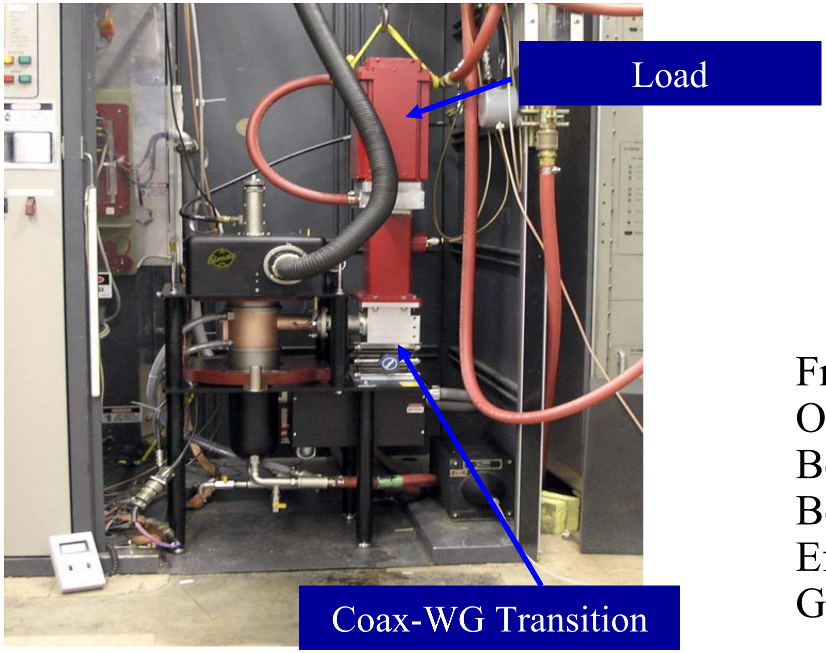
- A 5 MW L-band HOM IOT has superior performance characteristics when compared to any linear beam device
  - Smallest footprint, 1/3 the size of the MBK → lowest cost
  - Less than 1/3 the cooling infrastructure required
  - 60 kW less power required (per 10 MW)
  - At ~11¢ kW-hr, 50% uptime → $30,000^{00}$ /year/10MW savings

- For Qty 600, 10 MW peak, 150 kW average power HOM IOTs (operating at 8 MW, 120 kW)
  - 36 MW less prime-power infrastructure / usage
  - At ~11¢ kW-hr, 50% uptime → $18M /year saved

- Development of HOM IOT technology for ILC should be a high priority

Second Generation Sources – HOM IOT

- IOT's at L-band: this IOT will be used to drive TESLA type SC cavities for CW machines being developed now
- A pulsed version would be purchased to drive a pair of 5 MW ILC HOM IOTs



Frequency	1300 MHz
Output Power	30 kW CW
Beam Voltage	34 kV
Beam Current	1.4 A
Efficiency	64%
Gain	21 dB

RF source selection for the ILC

- Conclusion
  - Several examples of flexible manufacturing to meet peak demand were shown
  - The VKL-8301 10MW TESLA MBK was described
  - Second-generation sources for ILC were described
    - 10 MW 12 to 18 beam MBK
    - 5 MW L-band HOM IOT
  - *The benefits of IOT technology should make this a priority for ILC R&D funding*